

LATE PALEOCENE IN THE OTWAY BASIN: BIOSTRATIGRAPHY AND AGE OF KEY MICROFAUNAS

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SUMMARY

A planktonic foraminiferal fauna from below the Rivernook Member of the Dilwyn Formation in Victoria is important in earliest Tertiary correlations and age determinations in the Otway Basin. This fauna and the Rivernook fauna previously described are no younger than the *Truncorotaloides aequa* zone and its equivalents in tropical and Mediterranean sequences, and no older than the *Truncorotaloides velascoensis* zone. A review of recent studies indicates that both assemblages are older than Cuisian and that an Upper Paleocene (Ilerdian) age is still justified. There is some doubt about the ancestry of *Pseudohastigerina*, and the important *Pseudohastigerina* Datum seems to lie within the Upper Paleocene rather than at the Paleocene/Eocene boundary.

INTRODUCTION

There are relatively few horizons in the earliest Tertiary of the Otway Basin to which an age can be given. Two of the marine ingressions in a paralic sequence were dated as Paleocene but only one, the Rivernook Member of the Dilwyn Formation, has a reasonably common and diverse planktonic foraminiferal fauna (McGowran, 1965, 1968b, 1969).

Recognition of "Middle Paleocene" and "Upper Paleocene" right across the Otway Basin (mostly in the sub-surface) depends heavily on these age determinations (Taylor, 1970a, b). Palynological biostratigraphy (Harris, 1965, 1970, pers. comm.) extends correlations far beyond the known occurrences of planktonic or benthonic foraminifera, into Tasmania to the south, Queensland to the north, and the Lake Eyre region to the northwest. The next horizon in the succession to which an age has been given is regarded as early Middle Eocene (Ludbrook and Lindsay, 1969; McGowran, Harris and Lindsay, 1970).

So long as planktonic foraminiferal assemblages are found only in sporadic ingressions (Taylor, 1967) they cannot be assumed to represent the total open ocean fauna of the region at the time, nor can species ranges (as shown by Ludbrook, 1967, fig. 2) be known meaningfully in the region. The open ocean fauna furthermore was marginal to the tropics where species diversities were highest and potential biostratigraphic refinement greatest.

For all of these reasons new data on planktonic foraminifera have a pervading significance for local stratigraphy. This paper discusses an assemblage from just below the Rivernook Member of the Dilwyn Formation at Princetown, Victoria. It is necessary at the same time to discuss recent studies on late Paleocene chronostratigraphy so as to determine what can be meant by the terms "Upper Paleocene" and "Lower Eocene" and what is meant here.

WANGERRIP GROUP

In the Pebble Point to Princetown section in western Victoria (Baker, 1953, Singleton, 1967) the Pebble Point Formation is overlain by the Dilwyn Formation (fig. 1). All samples studied palynologically by Harris (1965) included organic-walled microplankton, so that the environment was at least "marginal marine" throughout. Episodic ingressions (Taylor, 1967) are manifested by horizons

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SECTION (1)		LOCAL BIOSTRATIGRAPHY (2)	
DILWYN FORMATION Dark carbonaceous and pyritic sandy clays. Approx. 600 feet exposed.	PRINCETOWN MEMBER	Q	<i>Planorotalites cf. pseudomenurdi</i>
	'Trochocyathus Bed'	R	<i>Planorotalites chapmani</i> s.s.
	RIVERNOOK MEMBER	S	<i>Truncorotaloides aequa</i> (3,4)
	'RIVERNOOK A'	T	<i>Truncorotaloides aff. acuta</i> (4)
PEBBLE POINT FORMATION Ferruginous grits, glauconitic sandstones, silts, shales; two units with horizon of shelly fossils at base of upper. Approx. 80 feet.		U	<i>Planorotalites chapmani ehrenbergi</i> (3)
(Lower Cretaceous)			
(1) See Baker 1953, Singleton 1968.			
(2) Taylor zonules, in Singleton 1968 and pers. comm. For palyno-biostratigraphy, see Harris 1970.			
(3) Faunas described by McGowran 1965.			
(4) Planktonic foraminiferal assemblages discussed herein.			

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Fig. 1. Outcropping section at Princetown, Victoria.

with calcareous macrofaunas and microfaunas. The two foraminiferal assemblages monographed (McGowran, 1965) come from the Pebble Point Formation and the Rivernook Member of the Dilwyn Formation. These and other fossiliferous horizons are good evidence for sporadically open-marine conditions, as shown briefly but clearly by Taylor (1967). Copiapite is common and appears to have derived from pyrite; the possible release of sulphuric acid would destroy calcareous tests (Taylor, 1965). However, the "marine horizons" appear to be real and not merely relics from an initially more complete fossil record because they are widespread in the Otway Basin and can be recognised in borehole sections (Taylor, 1970a, b). The concept of periodic ingressions in a paralic regime (Taylor, 1967) would seem more accurate than a relatively simple transgressive-regressive cycle (Bock and Glenie, 1965, Glenie et al., 1968). Taylor's biostratigraphic scheme, based on the section in the Latrobe bore at Princetown, was applied to the outcropping section (in Singleton, 1967) and is included here in an updated form (pers. comm. from Mr. Taylor). Zonule Q is acknowledged by Taylor as possibly Lower Eocene in age. There is insufficient evidence at present to date Zonules Q and R; more material is needed particularly of the name fossils.

PRE-RIVERNOOK PLANKTONIC ASSEMBLAGE

Taylor's Zonule T (fig. 1) is based on a bed which he found below the Rivernook Member and designated informally as "Rivernook A". Usually it is concealed by beach sand and remained unknown since the first studies on the section by C. S. Wilkinson a century ago. Taylor found a planktonic assemblage in Rivernook A, not so rich in specimens as the Rivernook (McGowran, 1965) but excellently preserved. The rock is a distinctively green, slightly indurated clay with silt, glauconite and mica.

Prolonged search yielded excellent specimens although their number is low. The following were identified (specimen numbers included); generic nomenclature is partly after McGowran (1968a) in this list and in the following discussion.

Subbotina patagonica (Todd and Kniker) (10); *S. aff. linaperta* (Finlay) (1); *Subbotina* sp. (2); *Planorotalites planoconica* (Subbotina) (5); *Pseudohastigerina wilcoxensis* (Cushman and Ponton) (11); *Truncorotaloides* (*Acarinina*) *esnaensis* (LeRoy) (7); *T. (Acarinina)* cf. *nitida* (Martin) (5); *Truncorotaloides* sp. (9); *T. (Morozovella) wilcoxensis* (Cushman and Ponton) (16); *T. (Morozovella) aequa* (Cushman and Renz) (3); *T. (Morozovella) aff. acuta* (Toulmin) (3); *Chiloguembelina* spp. (22) including morphotypes *crinita* (Glaessner), *wilcoxensis* (Cushman and Ponton), *midwayensis* (Cushman), *trinitatis* (Cushman and Renz).

Brief taxonomic notes on this assemblage are included at the end of the report; comments are based also on the collections from the Rivernook Member described previously.

Rivernook A contains, in addition to typical Rivernook elements, the important species *Truncorotaloides aff. acuta* and *Pseudohastigerina wilcoxensis*, one only of the latter having been recorded previously (as *Globigerina pseudoiota* Hornibrook) from the Rivernook Member.

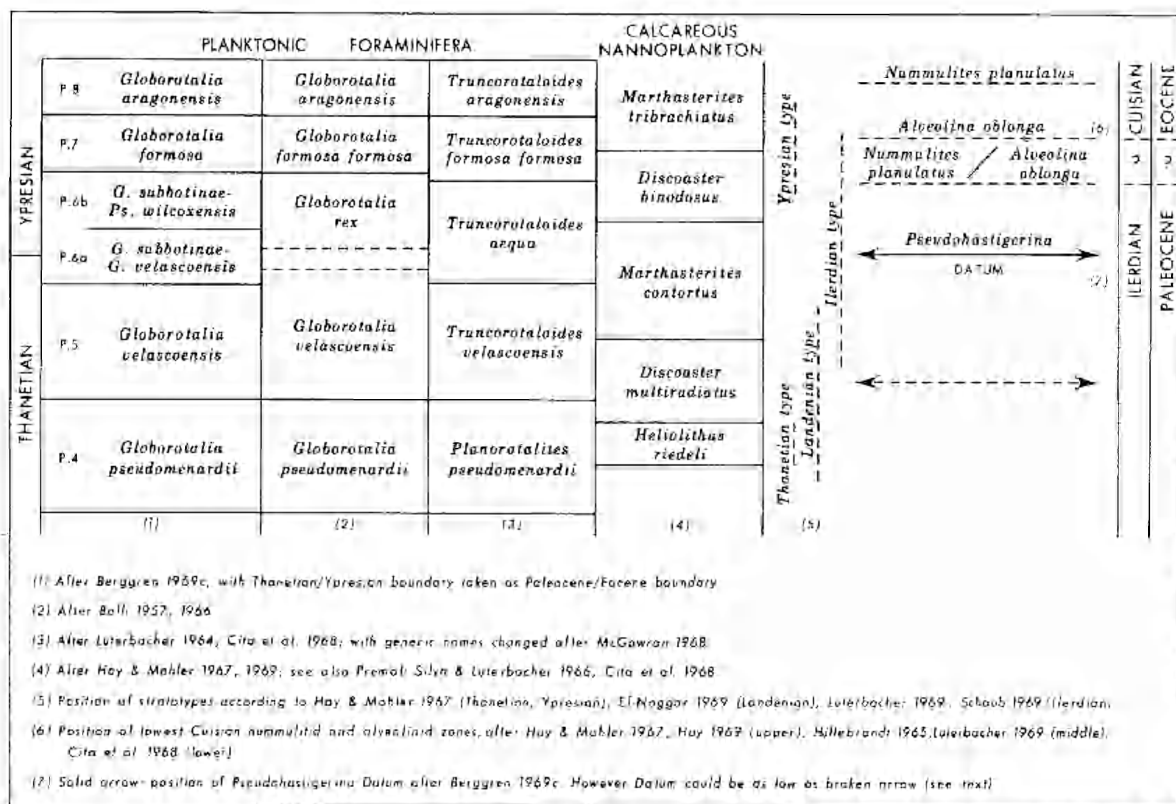
No nanofossils were found in a sample kindly prepared by Dr. H. Hekel (Geol. Surv. Queensland).

COMPARISON WITH THE BASHI MEMBER OF THE HATCHETIGBEE FORMATION IN ALABAMA

Currently the Rivernook Member is correlated with the *Truncorotaloides velascoensis* zone of low latitudes (McGowran, 1968b, 1969). Previously attention was drawn to a considerable faunal similarity to the Nanafalia Formation in Alabama (*Planorotalites pseudomenardii* zone). Figure 2 includes all the biostratigraphic units mentioned in the following discussion.

The planktonic assemblages in the U.S. Gulf and Atlantic coastal sections are rich in acarininids, but all of those described by Loeblich and Tappan (1957), Olsson (1960) and Nogan (1964) contain *P. pseudomenardii* and so belong in the zone of this name. None is known to occur in the *Truncorotaloides velascoensis* zone which, indeed, has not been clearly recognised (Berggren, 1965). There is one possible exception in New Jersey (Olsson, 1969). The Bashi Member of the Hatchetigbee Formation in Alabama, separated from the Nanafalia by the Tusahoma (without planktonics) has a rich acarininid fauna. The presence of *Truncorotaloides subbotinae*, *T. wilcoxensis* and *Pseudohastigerina wilcoxensis* has caused Berggren (1965, 1969b) to place the Bashi above the *Truncorotaloides velascoensis* zone and to date it as earliest Lower Eocene.

A sample of Bashi from Ozark, Alabama, has a rich planktonic fauna. It includes *Pseudohastigerina wilcoxensis* (Cushman and Ponton), acarininids matching the morphotypes *Truncorotaloides (Acarinina) pseudotopilensis*,



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Fig. 2. Biostratigraphy and chronostratigraphy pertinent to correlation and age of Rivernook horizons.

esnaensis, *soldadoensis*, *pentacamerata*, *gruelli* and others, *T. (Morozovella) wilcoxensis* (Cushman and Ponton), *T. aequa* (Cushman and Renz), *T. subbotinae* (Morozova), *T. pusilla laevigata* Bolli, *T. aff. acuta* (Toulmin), *Chiloguembelina wilcoxensis* (Cushman and Ponton), *Ch. milwayensis* (Cushman) s.l.

The only significant absence, with respect to the Rivernook assemblages, is *Chiloguembelina trinitatensis*. The main components not found in Rivernook or Rivernook A are some acariniid morphotypes and the keeled *Truncorotaloides subbotinae-formosa* group.

The Rivernook and Rivernook A assemblages compare more closely with this assemblage than with the assemblage from the Nanafalia illustrated by Loeblich and Tappan (1957).

CORRELATION AND AGE

There are several problems involved in the decision between a Paleocene and a Lower Eocene age for Rivernook A and the Rivernook Member.

(1) Some important species are absent or poorly represented. Comparisons are best with other assemblages outside the tropical belt and the Bashi assemblages now seems closest. Correlations with biostratigraphic sequences in e.g. the Caribbean (Bolli, 1957) or Mediterranean (Luterbacher, 1964; Cita et al. 1968) are made rather difficult. That there is a climatic imprint on these mid-

latitude faunas is indicated by the abundant acariniids (although there is good evidence that regressiveness has a converging effect). The absence of a particular species is less likely to mean that an assemblage lies outside its time range, so that negative evidence can be more misleading than in the tropics.

(2) Unless a correlation can be made directly with a classical stratotype of importance in time-stratigraphic classification (a first-order correlation; Reiss 1966) then the problem of age remains. It is not sufficient to correlate an horizon with e.g. the "*Truncorotaloides velascoensis* zone", no matter how good the correlation may be; palynologists, basin-study compilers and all other workers need the age, e.g. "Upper Paleocene". This link in the chain of correlations back to classical sections involves other fossil groups. Recent studies on calcareous microfossils are relevant here, as well as in indicating that the Bashi is somewhat older than has been concluded on the planktonic foraminiferal evidence.

As noted above, Berggren has suggested that the Bashi correlates with the "*Globovalia rex*" zone in Trinidad (Bolli, 1957), *T. (M.) subbotinae* (= *rex*) and *T. (?M.) wilcoxensis* being common to both and neither occurring in the *Truncorotaloides velascoensis* zone. Known "species" ranges show a pattern of extinction and radiation in keeled globorotaliids with the *velascoensis-acuta-occlusa* (*simulacilis*) group being replaced by the newly radiating *subbotinae-marginodentata-formosa* group (Berggren, 1968). But there is a distinct overlap in the *Truncorotaloides velascoensis* and *T. aequa* zones (Luterbacher, 1964, 1966; Cita et al., 1968). Berggren (1969 a, b) has noted that the last members of the *velascoensis-acuta* group overlap with the first *subbotinae*. The association of *T. aff. acuta* with *T. subbotinae-marginodentata* in the Bashi suggests that this assemblage is no younger than this interval of overlap.

Since *T. aff. acuta* occurs in Rivernook A the same criteria apply. The apparent absence of *T. aff. acuta* from the Rivernook Member could mean that it is slightly but significantly younger (by biostratigraphic analysis; obviously it is younger by superposition), but in a mid-latitude, paralic sequence this reasoning is dangerous.

It is less clear that the Bashi and Rivernook A are no older than the "*Globovalia rex*" zone. *T. pusilla laevigata* in the Bashi compares excellently with topotypes, and this species is regarded as distinctively Paleocene (e.g. Berggren, 1968, fig. 1). *T. wilcoxensis* is regarded generally as a post-*Truncorotaloides velascoensis* zone species (e.g. Berggren, 1968) but the *aequa-wilcoxensis* assemblage in the northern Caucasus (Almarina, 1963) correlates in part with the *Truncorotaloides velascoensis* zone (Luterbacher, 1964). *T. subbotinae* and *T. formosa gracilis* are recorded herein from the Bashi, but their distinctness from *T. marginodentata* and *T. aff. formosa gracilis* (Luterbacher, 1964, 1966) is too tenuous to allow confident discrimination between the *T. velascoensis* and *T. aequa* zones.

The acariniid elements typical of Lower Eocene faunas and found in the Bashi have much in common with similar assemblages in the *Planorotalites pseudomenardii* zone, as noted above, and the complex was well established in the *Truncorotaloides velascoensis* zone (e.g. Berggren, 1969c). *Acarina* and *Truncorotaloides* s.s. seem to have persisted in higher latitudes beyond the level of extinction in the tropics (Berggren, 1969b). There is evidence for this preference for cooler waters in the Middle-Upper Paleocene range of this group. Acariniids are richer and more diverse in the U.S. Gulf and Atlantic coastal region than in Trinidad. As a broad generalisation the Lower Eocene is relatively more regressive than the Upper Paleocene or the Middle Eocene throughout the world. This may have a climatic basis with acariniids becoming more characteristic of low-altitude sequences by invasion at about the time tropical elements

(particularly the *T. velascoensis* group) were declining. A "marginal" assemblage could have a Lower Eocene aspect yet be slightly older, and phyletic lineages in *Acarinina* are not known well enough to exclude this possibility. Assemblages to which it applies include the Bashi and Rivernook, and also the *Globorotalia subbotinae* zone in New Jersey (Olsson, 1969).

It is concluded on foraminiferal evidence that the Rivernook A fauna is no younger than the Bashi, and that the Bashi is no younger than the *Truncorotaloides aequa* zone (*sensu* Luterbacher; see fig. 2) but could well be of the same age as the *T. velascoensis* zone.

Thus the foraminiferal evidence need not contradict nannofossil evidence for correlating the Bashi with the *T. velascoensis* zone. Branlette and Sullivan (1961) regarded the Bashi nannoflora as transitional between their *Discoaster multiradiatus* and *D. tribrachiatus* zones with greater similarity to the former (Upper Paleocene). Hay (1964) placed the Bashi tentatively near the top of the *Marthasterites contortus* zone (which is shown to fill a gap between the Branlette and Sullivan zones; Hay et al., 1967, fig. 2) and slightly above the "*Globorotalia rex*" zone in Trinidad. More recently (Hay and Mohler, 1967; Hay et al., 1967) the Bashi is placed in the *Discoaster multiradiatus* zone, which includes also the *Truncorotaloides velascoensis* zone in Trinidad and northern Italy (but see Cita et al., 1968), and this zone and the *Planorotalites pseudomenardii* zone in the Velasco Shale in Mexico. Indeed, on the correlation of zones presented by Hay and Mohler (1969) the Bashi would fall low in the *T. velascoensis* zone. The "*Globorotalia rex*" zone in Trinidad was said to have a nannofossil assemblage characteristic of the upper part of the *Marthasterites contortus* zone.

The Paleocene/Eocene boundary was placed at the top of the *Truncorotaloides velascoensis* zone (Bolli, 1957, 1966; Berggren (1969 a-c) has moved it slightly higher because of the important overlap noted above, to within subzone P6a (*subbotinae-velascoensis*) (fig. 2). This is regarded as being also the Thanetian/Ypresian Stage boundary, but the evidence for correlating stratotypes of these or other stages (Sparnacian, Landenian) with planktonic foraminiferal zones is very weak, and the evidence from nannofloras shows a gap. Sequences in north-west Europe pertinent to chronostratigraphic classification have, at best, restricted cooler-water and/or regressional assemblages dominated by acarininids and poor or lacking in significant keeled globorotaliids (Berggren, 1960, 1969b; Brönnimann et al., 1968; Moorkens, 1968; El-Naggar, 1969). None of the species identified and discussed by Moorkens from the Ypresian demonstrate that this stage is younger than the Thanetian (as it clearly is); several, indeed, occur as low as the *Planorotalites pseudomenardii* zone. The nannofloras indicate that the type Thanetian lies in the *Heliolithus riedeli* zone and that the type Ypresian is as low as the *Discoaster binodosus* zone (Hay and Mohler, 1967; Bignot and Lezard, 1969).

In the Paris Basin, the nummulitid and alveolinid faunas of the Cuisian Stage can be correlated with faunas in the Mediterranean region and integrated with evidence from planktonic microfossils. The Paleocene/Eocene boundary has been drawn at the base of the Cuisian Stage, at the base of the parallel zones of *Alveolina oblonga* and *Nummulites planulatus* (Hottinger and Schaub, 1960; Hottinger, Lehmann and Schaub, 1964). The Ilerdian stage of Hottinger and Schaub then is the highest chronostratigraphic unit in the Paleocene. With respect to the biostratigraphic systems based on planktonic microfossils, this boundary has been placed at three closely spaced but rather distinct levels (fig. 2). The *Nummulites planulatus* zone has been identified in the Schlierenflysch in Switzerland within the *Marthasterites tribrachiatus* zone (Hay and Mohler, 1967, and refs. therein) and within its middle part (Hay, 1969). The latter zone is relatively

large (Hay and Mohler, 1969) and the base of the Cuisian could be as high as the *Truncorotaloides aragonensis* zone. However, Bignot and Le Calvez (1969) have recorded *T. subbotinae-marginodentata* from the Cuisian (see also Brönnimann et al. 1968) indicating that the Cuisian should include at least part of the *Truncorotaloides formosa* zone; this is consistent with the range of the Neridian according to Hillebrandt (1965) and Luterbacher (1969). Finally, Schaub (in Cita et al. 1968) has identified the basal Cuisian at an horizon within the *Discoaster binodosus* zone, at about the top of the *Truncorotaloides aequa* zone.

Clearly, there are still problems in relating biostratigraphic systems to a consistent chronostratigraphic framework. In chronostratigraphic enquiry there must be, ultimately, a balance between historical weight and practical value (i.e. circumglobal recognition) and a formal decision as to the best position for the boundary between two stages. It would seem at present that, of the alternatives for a Paleocene/Eocene boundary, the Neridian/Cuisian boundary is the most useful and promising for biostratigraphic correlation, the Neridian fulfilling stratigraphic requirements (Schaub, 1968, 1969; Luterbacher, 1969). The *Truncorotaloides aequa* zone is in the Neridian. This means that the Bashi Marl in Alabama and the Rivernook and Rivernook A assemblages in Victoria are Upper Paleocene in age.

THE PSEUDOHASTIGERINA DATUM

The current trend in Tertiary biostratigraphy is somewhat away from the use of zones, defined in the various ways listed in codes and texts. The differences between mid-latitudes and the tropics, and between nearshore and deep-sea assemblages, account for much of the confusion among existing biostratigraphic systems and the typological, agnostic ("objective") approach to morphotype recognition and definition accounts for some more. Greater attention is being paid to "datum lines" (or "surfaces") particularly as marked by the emergence of a species from a known ancestor in a well-documented phyletic series (either successional shift in observable morphological range or bifurcation, speciation). Total-range zones are the best if the index species has a short range in time ("life") but the lower boundary is the better in any case because it represents a unique event in evolution, whereas the upper boundary is based on extinction which is a "plane" only until demonstrated otherwise. (In practice, some extinctions such as the mass extinction of planktonic species at the top of the Maastrichtian have excellent correlational value.)

One such datum is represented by the first appearance of *Pseudohastigerina wilcoxensis* at or close to the Paleocene/Eocene boundary. It was considered to coincide with the extinction of *Truncorotaloides velascoensis* (Berggren, 1964), and still marks the base of the Eocene even though the ranges of certain other species are changed slightly (Berggren, 1969c) (fig. 2). The value of the datum lies further in the occurrence of *Pseudohastigerina* at latitudes and in facies where important species are not found, and also in that the immediate ancestry has been inferred (Berggren et al., 1967). In the following discussion doubt is cast on the ancestry and on the time of the first appearance.

According to Berggren et al. (1967) *Planorotalites chapmani* (Parr) is the immediate ancestor of *Pseudohastigerina wilcoxensis*. The latter species includes distinctly trochospiral as well as pseudoplanispiral forms (notes on species, below). Occasional specimens with slightly more compressed chambers than usual (Berggren et al., 1967, text-fig. 2d-f) are the only published, visual evidence of ancestry in *P. chapmani*, although Berggren (1964-1969c) has recorded the range of *P. chapmani* as overlapping slightly with *P. wilcoxensis* with some intergradation (e.g. in the Bashi).

This raises the question of the identity and morphological range of *Planorotalites chapmani*. In the original material (McGowran, 1964) this species has a compressed test with rather acute periphery, giving arrowhead-shaped chambers in profile, and it has an imperforate marginal band (McGowran, 1968a, pl. 4, fig. 15, 16). *Globorotalia troelseni* Loeblich and Tappan is a junior synonym and this compressed form appears not to range above the *Planorotalites pseudomenardii* zone (Berggren, 1964). "*G. elongata* Glaessner" auctt. is also synonymous with *P. chapmani*, at least in part (McGowran, 1964). Recently figured specimens of *P. chapmani* from the *Planorotalites pseudomenardii* zone (Berggren et al., 1967, pl. 1) agree with typical *P. chapmani* except that a fully perforate margin is shown (drawing only, not photograph or thin section) and the specimens are small. There seem to be no convincing records published to support the contention that *P. chapmani* ranges well above the *P. pseudomenardii* zone. In Western Australia *P. chapmani* is replaced in the *P. simplex* zone (correlated with the *Truncorotaloides velascoensis* zone; McGowran, 1968b) by a closely related but distinct species identified as *Planorotalites simplex* Haque (McGowran, 1968a, pl. 4, fig. 19-20, 22). *P. simplex* occurs at the same level in West Pakistan (Haque, 1956; see McGowran, 1968b), and in Austria ("*G. elongata*" of Hillebrandt, 1962). Hillebrandt (1965) records *P. simplex* from the *Planorotalites pseudomenardii* and *Truncorotaloides velascoensis* zones in Spain. Although Hay (1960) records "*Globorotalia elongata* Glaessner" from the *Truncorotaloides velascoensis* zone in Mexico, Berggren et al. note the similarity of a figured specimen (Loeblich and Tappan, 1956, pl. 63, fig. 2) to *Globanomalina simplex*; it is not a typical *P. chapmani*. Typical *P. simplex* appear to range down to within *Planorotalites pseudomenardii* zone but, particularly on the Western Australian evidence, *P. simplex* appears to be distinct from and mostly successional to *P. chapmani* rather than a "morphological variant" of the latter as suggested by Berggren et al. Very small specimens in the Bashi are not convincing evidence of a *P. chapmani*-*P. wilcoxensis* phyletic transition, which remains inferential. Specimens identified as *Globorotalia imitata* Subbotina (see especially Loeblich and Tappan, 1957; McGowran, 1965) show very close similarity to *Pseudohastigerina* of the more trochospiral, asymmetrical type, and suggest this species as a likely ancestor. A similarity in wall thickness increases this similarity, in contrast to *P. chapmani* (McGowran, 1968a, pl. 4). However, in the early Middle Eocene of South Australia assemblages of *P. wilcoxensis* include individuals, seemingly intergrading with the typical form, which would fit quite easily in a Paleocene population of *P. imitata*. Cordey et al. (1970), however, maintain the alternative view that *P. chapmani* is the ancestor of *Pseudohastigerina*.

P. wilcoxensis is well known in the *Truncorotaloides aequa* zone and its equivalents (Berggren et al., 1967; Berggren, 1969a-c; Beckmann et al., 1969; Hillebrandt, 1965). A few poor specimens have been found in a sample from the "*Globorotalia rex*" zone in Trinidad. Reasons given above for making the Ilerdian/Cuistau boundary the Paleocene/Eocene boundary mean that these occurrences are of Paleocene rather than Eocene age. Nanofossil evidence for correlating the Bashi with the *Truncorotaloides velascoensis* zone indicates a still lower first occurrence. There is other evidence for this. *Globanomalina ovalis* Haque s.s. is a poorly known taxon (see especially Berggren et al., 1967) but must be very close to *Pseudohastigerina*, yet it is associated near the base of its range (Salt Range, Pakistan) with *Planorotalites pseudomenardii* (see McGowran, 1968b for discussion on Haque, 1956). Latif (1964) records "*Hastigerina pseudoiota* (Hornibrook)" from probable Upper Paleocene, also in Pakistan (McGowran, 1968b). "*Globorotalia* (*Turborotalia*) cf. *pseudoiota*" was found associated with

Planorotalites pseudomenardii in the equatorial Atlantic (Cifelli et al., 1968). Charrier and Lahsen (1968, 1969) recorded a planktonic assemblage from the lower Agua Fresca Formation, southern Chile, with *Globanomalina pseudoiota*, *G. compressa* (Plummer) and "*G. membranacea* (Ehrenberg)" (see notes on species, below). This assemblage has a Paleocene aspect. No *Subbotina patagonica* were reported whereas this species is characteristic of the Agua Fresca (Herm, 1966) and associated with *Pseudohastigerina wilcoxensis*, indicating a Lower Eocene age for the upper part (Berggren, 1969b). Thus, negative evidence also indicates a Paleocene age for Charrier and Lahsen's assemblage. On the other hand, the associated nannofossils have an early Eocene aspect, and the presence of *Discoaster tribrachiatus* suggests an age of no older than *D. binodosus* zone. The first occurrence of *Pseudohastigerina wilcoxensis* in New Zealand is one of Jenkins' main datum planes (Jenkins, 1966) but its actual position is difficult to evaluate from published ranges (Jenkins, 1965). The *Globanomalina wilcoxensis* zone was correlated with the *Truncorotaloides* "rex"-*T. formosa* interval in Trinidad. However, the range of the *T. velascoensis* group appears to be more restricted in New Zealand than Jenkins allows because *P. pseudomenardii* extends above it; thus there is no evidence for a *Truncorotaloides velascoensis* zone. Either important species are restricted or missing for climatic reasons, or part of the section is missing. That is, the problems appear to be the same as in Victoria.

In conclusion, it can be said that there is still room for legitimate doubt about the immediate ancestry of *Pseudohastigerina*, although there is no doubt that it arose from the early Tertiary genus *Planorotalites*. Further studies on its phylogeny and classification are needed. It seems, however, to have emerged during the Upper Paleocene and below the top of the *Truncorotaloides velascoensis* zone.

NOTES ON SPECIES AND MORPHOTYPES

Subbotina patagonica (Todd and Kniker): agrees well with original description and recently identified Lower Eocene forms (Berggren, 1969b) except that the aperture can be even higher.

Subbotina aff. *linaperta* (Finlay): Most Rivernook specimens are not so compressed laterally as specimens of *S. linaperta* from the Bortonian of New Zealand and the refigured holotype from the same level (Hornibrook, 1958a); this comment applies to most pre-Middle Eocene records of *S. linaperta*. *S. trivialis* (Subbotina) may be added to the list of morphotypes given previously.

Planorotalites planoconica (Subbotina): probably a better name for most of Rivernook *P. chapmani* (Parr). Close to but distinct from Pebble Point *P. chapmani* compared with *ehrenbergi* (Bolli) or *haunsbergensis* (Colrubandt). The latter is closer to, but seemingly distinct sample-wise from, *P. australiformis* (Jenkins) from the Middle Eocene of South Australia. It is also probably identical with "*Globorotalia membranacea* (Ehrenberg)" of Charrier and Lahsen (1968). Since *P. australiformis* is recorded from the Upper Paleocene to early Middle Eocene in New Zealand (Jenkins, 1965) the significance of the Pebble Point species as a Middle Paleocene indicator is reduced. Whereas *Planorotalites chapmani ehrenbergi/haunsbergensis* occupies a fairly clearcut position in tropical sections (Middle Paleocene; ancestor of *P. pseudomenardii*), and in New Jersey (Olsson, 1969), a lineage extends to the Middle Eocene in mid-latitudes and needs detailed study.

Pseudohastigerina wilcoxensis (Cushman and Ponton): agrees with *Globigerina pseudoiota* Hornibrook (1958 a, b). Aperture and coiling show strong asymmetry (see also Hornibrook, l.c.; Latiff, 1964; Charrier and Lahsen, 1968, etc.)

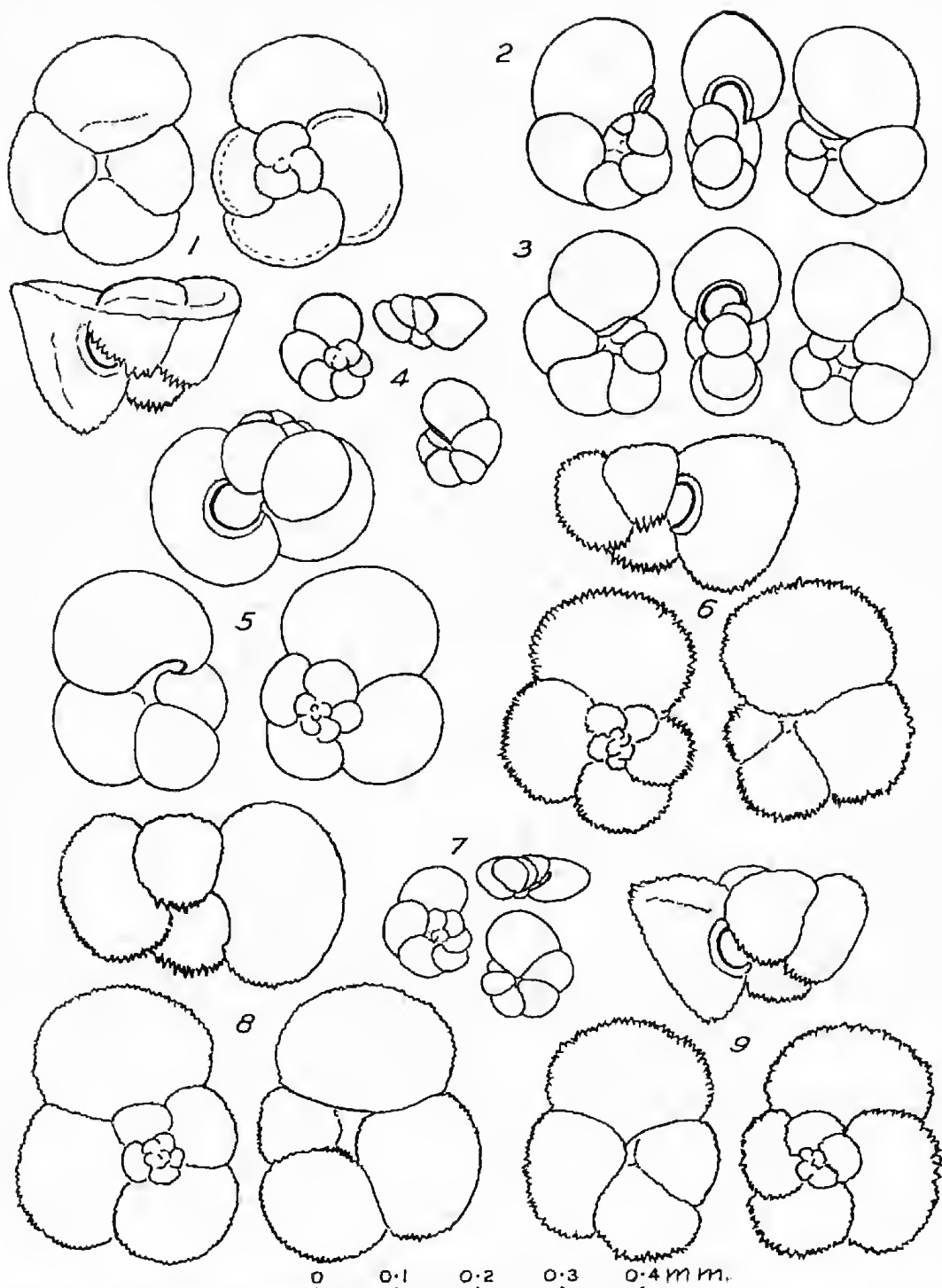


Fig. 3. Planktonic foraminifera from the Rivernook A horizon. Each specimen shown in three views; 1, *Truncorotaloides* (Morozovella) aff. *acuta* (Toulmin). 2, 3, *Pseudohastigerina wilcoxensis* (Cushman & Ponton) of the asymmetrical, *pseudoiota* type. 4, 7, *Planorotalites planoconica* (Subbotina). 5, *Subbotina patagonica* (Todd & Kniker). 6, *Truncorotaloides* (M.) *wilcoxensis* (Cushman & Ponton). 8, *Truncorotaloides* (Acarinina) *esnaensis* (Leroy). 9, *Truncorotaloides* (M.) *aequa* (Cushman & Renz).

and there are none of the almost planispiral variants of *P. wilcoxensis* figured from New Zealand and New Jersey assemblages (Berggren et al., 1967) and observed together with the others in topotype material (Bashi Member of Hatchetigbee, Alabama). This primitive aspect persists into the early Middle Eocene in South Australia.

Berggren et al. suggested that *G. pseudoiota* should be placed in synonymy with *P. wilcoxensis*, but further study (Cordey et al., 1970) indicated that it may be better placed in *P. sharkriverensis* Berggren and Olsson. The early members of the lineage are rather problematical, especially in Australia as acknowledged by Cordey et al., and the name *P. wilcoxensis* is tentatively maintained here pending further clarification. Incidentally, these authors' discussion of my (1968a, fig. 1) "view on the phylogeny of the pseudohastigerinids" goes well beyond the original intention; the "view" was merely to use sufficient morphotypes to indicate an evolutionary trend for the purposes of genus-group and family-group classification.

Truncorotaloides (Acarinina): acarininids are notoriously variable and intergradational in the Upper Paleocene and Lower Eocene (see, however, useful discussion of synonymy by Berggren, 1968). *T. (A.) esnaensis* and *T. (A.) cf. nitida* in Rivernook A may be distinct, but much larger assemblages in Rivernook proper range from *pentacamerata* Subbotina or *soldadoensis* Brönnimann through a "central" group of *esnaensis*, *intermedia* Subbotina, etc., to *triplex* Subbotina, *pseudotopilensis* Subbotina, etc. Tightly coiled pre-Middle Eocene forms referred by several authors to *primitiva* Finlay can mostly be distinguished from this species.

Truncorotaloides sp.: small, five-chambered, rounded (cf. *pentacamerata* Subbotina) or truncate and flattened spirally (cf. *apanthesma* Loeblich and Tappan). Occurs in Rivernook and also Bashi.

Truncorotaloides (M.) *aequa* and *T. (M.) wilcoxensis*: lumped previously, but specimens in Rivernook proper compare very well with topotypes of both forms. Same in Rivernook A.

T. (M.) aff. acuta: strongly truncate, highly conical chambers, angular and slightly keeled margin, umbilical shoulders with slight thickening. Compares well with topotypes of *T. acuta* but lacks strong thickening of shoulders seen in largest and in those closest to *velascoensis* (Cushman) (see e.g. Loeblich and Tappan, 1957). Not found in Rivernook proper but occurs in Bashi. Very similar to specimens in *Planorotalites pseudomenardii* zone in south India which in turn provide link with *T. conicotruncata* (Subbotina).

Chiloguembelina spp.: morphotypes listed appear to be matched in Rivernook A and Rivernook proper (see Beckman, 1957), but consistent separation into coherent taxa is rather doubtful even with excellent material.

CONCLUSIONS

(1) The Rivernook A assemblage is similar to the Rivernook assemblage except that there are fewer specimens, *Truncorotaloides* aff. *acuta* is present and *Pseudohastigerina wilcoxensis* is relatively well represented.

(2) Both assemblages are characteristic of acarininid-rich, mid-latitude faunas in the early Tertiary, and the similarity with the Bashi Member of the Hatchetigbee Formation in Alabama is particularly striking.

(3) Recent studies of calcareous nannofossils indicate that the Bashi correlates with the planktonic foraminiferal zone of *Truncorotaloides velascoensis* rather than slightly higher. It is concluded on foraminiferal evidence also that the Bashi and Rivernook assemblages need be no younger, but that a range in

possible correlation including the *Truncorotaloides velascoensis* zone and (?lower) *Truncorotaloides aequa* zone is the most precise presently justified.

(4) The Ilerdian/Cuisian boundary seems to be the best position for the Paleocene/Eocene boundary. Both of the assemblages from the Dilwyn Formation are Ilerdian and therefore Upper Paleocene in age.

(5) The evolution of *Pseudohastigerina wilcoxensis* from *Planorotalites chapmani* has not been demonstrated completely and remains inferential. *Planorotalites imitata* is a possible alternative ancestor. The *Pseudohastigerina* Datum lies within the Upper Paleocene, not at the Paleocene/Eocene boundary. It could be close to the base of the Ilerdian.

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REFERENCES

- ALISTARICA, V. P., 1963. (Some peculiarities in the development of planktonic foraminifera and the zonation of the Lower Paleocene in the Northern Caucasus). *Vopr. Mikropaleont.* 7: 158-195 (in Russian).
- BAKER, G., 1953. The relationship of the *Cyclammina*-bearing sediments to the older Tertiary deposits south-east of Princeton, Victoria. *Mem. natn. Mus. Victoria* 18: 125-134.
- BECKMANN, J. P., 1957. *Chiloguembelina* Loeblich and Tappan and related Foraminifera from the Lower Tertiary of Trinidad, B.W.I. *Bull. U.S. natn. Mus.* 215: 83-96, pl. 21.
- BECKMANN, J. P., EL-HEINY, I., KIRDANY, M. T., SAID, R., and VIOTTI, C., 1969. Standard planktonic zones in Egypt. *Proc. 1st. Internat. Conf. Planktonic Microfossils, Geneva 1967*, Brönnimann, P. and Renz, H. H., Eds., 1: 92-103.
- BERGGREN, W. A., 1960. Some planktonic foraminifera from the lower Eocene (Ypresian) of Denmark and northern Germany. *Stockh. Contr. Geol.* 5 (3): 41-108, 13 pls.
- BERGGREN, W. A., 1964. Paleocene-Lower Eocene biostratigraphy of Luxor and nearby western Desert. *Petrol. Expl. Soc. Libya, 6 Annual Field Conf.*: 149-176, pls. 1, 2, Amsterdam.
- BERGGREN, W. A., 1965. Some problems of Paleocene-Lower Eocene planktonic foraminiferal correlations. *Micropaleontology* 11: 278-300, pl. 1.
- BERGGREN, W. A., 1968. Phylogenetic and taxonomic problems of some Tertiary planktonic foraminiferal lineages. *Tulane stud. Geol.* 6: 1-22.
- BERGGREN, W. A., 1969a. Biostratigraphy and planktonic foraminiferal zonation of the Tertiary system of the Sirte Basin of Libya, north Africa. *Proc. 1st. Internat. Conf. Planktonic Microfossils, Geneva 1967*, Brönnimann, P. and Renz, H. H., Eds. 1: 104-120.
- BERGGREN, W. A., 1969b. Paleogene biostratigraphy and planktonic foraminifera of northern Europe. *Ibid.* 1: 121-160.
- BERGGREN, W. A., 1969c. Rates of evolution in some Cenozoic planktonic foraminifera. *Micropaleontology* 15: 351-365.
- BERGGREN, W. A., OLSSON, R. K. and REYMENT, R. A., 1967. Origin and development of the foraminiferal genus *Pseudohastigerina* Banner and Blow, 1959. *Micropaleontology* 13: 265-288.
- BIGNOT, G. and LE CALVEZ, T., 1969. Contribution à l'étude des foraminifères planctoniques de l'Eocène du Bassin de Paris. *Proc. 1st. Internat. Conf. Planktonic Microfossils, Geneva, 1967*, Brönnimann, P. and Renz, H. H., eds., 1: 161-166.
- BIGNOT, G. and LEZAUD, L., 1969. Sur la présence de *Marthasterites tribrachiotus* dans l'Yprésien du bassin anglo-franco-belge. *Revue Micropaléont.* 12: 119-122.
- BUCK, P. E. and GLENNE, R. C., 1965. Late Cretaceous and Tertiary depositional cycles in south-western Victoria. *Proc. R. Soc. Vict.* 79: 153-163.
- BULLI, H. M., 1957. The genera *Globigerina* and *Globorotalia* in the Paleocene-Lower Eocene Lizard Springs Formation of Trinidad, B.W.I. *Bull. U.S. natn. Mus.* 215: 61-82, pls. 15-20.

- BULLI, H. M., 1966. Zonation of Cretaceous to Pliocene marine sediments based on planktonic foraminifera. *Bol. Inf. Asoc. Venez. Geol. Min. Petrol.* 9 (1): 3-32.
- BRAMLETTE, M. N. and SULLIVAN, F. R., 1961. Coccolithophorids and related nanoplankton of the Tertiary in California. *Micropaleontology* 7: 129-188.
- BRÖNNIMANN, P., CURRY, D., POMEROL, C., and SZÖTS, E., 1968. Contribution à la connaissance des Foraminifères planctoniques de l'Eocène (incluant le Paléocène) du Bassin Anglo-Franco-Belge. *Mém. Bur. Rech. Géol. Min. Paris* 58: 101-108.
- CHARRIER, R. and LAHSEN, A., 1968. Contribution à l'étude de la limite Crétacé-Tertiaire dans la Province de Magellan, extrême sud du Chili. *Revue Micropaléont.* 11: 111-120.
- CHARRIER, R., and LAHSEN, A., 1969. Stratigraphy of late Cretaceous-early Eocene, Seno Skytung-Strait of Magellan area, Magallanes Province, Chile. *Bull. Am. Ass. Petrol. Geol.* 53: 568-590.
- CIEELLI, R., BLOW, W. H. and MELSON, W. G., 1968. Paleogene sediment from a fracture zone of the Mid-Atlantic Ridge. *J. Mar. Res.* 26: 105-109.
- CITA, M. B., PREMOLI-SILVA, I., TROMARKINE, M., BULLI, H. M., LUTERBACHER, H. P., MOHLER, H. P. and SCHAUB, H., 1968. Le Paléocène de Paderno d'Adda. *Mém. Bur. Rech. Géol. Min. Paris* 58: 611-627.
- COWLEY, W. G., BERGQREN, W. A. and OLSSON, R. K., 1970. Phylogenetic trends in the planktonic foraminiferal genus *Pseudohastigerina* Banner and Blow 1959. *Micropaleontology* 16: 233-242.
- EL-NAGGAR, Z. R., 1969. New suggestions for the division and correlation of Paleocene strata by the use of planktonic foraminifera. *Proc. 1st Internat. Conf. Planktonic Microfossils, Geneva, 1967*, Brönnimann, P. and Renz, H. H., Eds., 2: 182-201.
- GLENNIE, R. C., SCHOFIELD, J. C. and WARD, W. T., 1968. Tertiary sea levels in Australia and New Zealand. *Palaeogeog., Palaeoclim., Palaeoecol.* 5: 141-163.
- HAEQUE, A. F. M., 1956. The foraminifera of the Banikot and the Laki of the Narmal Gorge, Salt Range, *Paleont. Pakist.* 1: 1-300.
- HAMUS, W. K., 1965. Basal Tertiary microfossils from the Princetown area, Victoria, Australia. *Palaeontographica* 115 (B): 75-106, pls. 24-29.
- HARRIS, W. K., 1970. Tertiary stratigraphic palynology, Otway Basin, Ch. 4 in *The Otway Basin in south-east Australia*, Spec. Bull. geol. Surv. S. Aust. Vict. (in press).
- HAY, W. W., 1960. The Cretaceous-Tertiary boundary in the Tampico Embayment, Mexico. *Proc. 21st Int. Geol. Congr., Sec. 5*: 70-77.
- HAY, W. W., 1964. Utilisation stratigraphique des Discoasteridés pour la zonation du Paléocène et l'Eocène inférieur. *Mém. Bur. Géol. Min. Paris* 28: 883-889.
- HAY, W. W., 1969. On defining boundaries between the Paleocene, Eocene and Oligocene. *Ibid.* 69: 197-200.
- HAY, W. W. and MOHLER, H. P., 1967. Calcareous nanoplankton from early Tertiary rocks at Pont Labau, France, and Paleocene-early Eocene correlations. *J. Paleont.* 41: 1505-1541, pls. 196-206.
- HAY, W. W. and MOHLER, H. P., 1969. Paleocene-Eocene calcareous nanoplankton and high-resolution biostratigraphy. *Proc. 1st Internat. Conf. Planktonic Microfossils, Geneva 1967*, Brönnimann, P. and Renz, H. H., Eds., 2: 250-253.
- HAY, W. W., MOHLER, H. P., ROTH, P. H., SCHMIDT, R. R. and BOUDREAUX, J. E., 1967. Calcareous nanoplankton zonation of the Cenozoic of the Gulf Coast and Caribbean-Antillean area and transoceanic correlation. *Trans. Gulf Cst. Ass. Geol. Soc.* 17: 428-480, 13 pls.
- HERM, D., 1966. Micropaleontological aspects of the Magellanese Geosyncline, southernmost Chile, South America. *Proc. 2nd W. Afr. micropalcont. Coll. (Ibadan, 1965)*, Leiden, E. J. Brill: 72-86.
- HILLEBRANDT, A. VON, 1962. Das Paleozän und seine Foraminiferenfauna im Becken von Reichenhall und Salzburg (Nördliche Kalkalpen). *Bayer. Akad. Wiss. Math.-naturwiss. Kl., Abh. N.F.* 108: 1-182, 15 pls.
- HILLEBRANDT, A. VON, 1965. Foraminiferen-Stratigraphie im Alttertiär von Zumaya (Provinz Guipúzcoa, N. W. Spanien) und ein Vergleich mit anderen Tethys-Gebieten. *Ibid.* 123: 1-62.
- HORNIBROCK, N. DE B., 1958a. New Zealand Upper Cretaceous and Tertiary foraminiferal zones and some overseas correlations. *Micropaleontology* 4: 25-38.
- HORNIBROCK, N. DE B., 1958b. New Zealand foraminifera. Key species in stratigraphy—No. B N.Z. J. Geol. Geophys. 1: 653-676.
- HOTTINGER, L. and SCHAUB, H., 1960. Zur Stufeneinteilung des Paleocäns und des Eocäns. Einführung des Ilerdien und des Biarritzien. *Eclog. geol. Helv.* 53: 454-579.
- HOTTINGER, L., LEHMANN, R. and SCHAUB, H., 1964. Données actuelles sur la biostratigraphie du Nummulitique Méditerranéen. *Mém. Bur. Rech. Géol. Min. Paris* 28: 611-632.

AGE DETERMINATION OF POUCH YOUNG AND JUVENILE KANGAROO ISLAND WALLABIES.

BY CLARE R. MURPHY* AND JANCE R. SMITH*

Summary

Repeated measurement of head, leg and foot lengths were made during the development of young Kangaroo Island wallabies (*Protemnodon eugenii*) of known age. The measurements were used to construct age regressions. Size was fairly closely correlated with age until the young were 320 days old but thereafter it had little value for age determination. The reliability of using the regressions to determine the age of young wallabies has been tested by using them to estimate the age of 14 young of known age. The largest error between the estimated and actual age of the young was about 5%. Growth proportions of captive and field-reared young were compared and these were found to be similar until the young were about 350 days old.